NSSSD: A New Semantic Hierarchical Storage for Sensor Data

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***Abstract*—Sensor networks usually generate mass of data, which if not structured for future applications, will require much effort on analytical processing and interpretations. Thus, storing sensor data in an effective and structured format is a key issue in the area of sensor networks. In the meantime, even a little improvement on data storing structure may lead to a significant effect on the lifetime and performance of the sensor network. This paper describes a new method for sensor storage that combines semantic web concepts, a data aggregation method along with aligning sensors in hierarchical form. This solution is able to reduce the amount of data stored at the sink nodes significantly. At the same time, the method structures sensed data in a way that we can respond to semantic web-based queries with less consumption of energy compared to previous conventional methods. Results show that, in some situations especially when the diversity of query responses and life of network are vital, the efficiency of our new solution is much better.**

Keywords— Knowledge modeling, sensor data, hierarchical storage

I. INTRODUCTION

Nowadays, the role of wireless technology is of great significance in a variety of areas. This accomplishment mostly relies on new technological advancements in sensor networks. In other words, sensors interact with each other in some specific network. Each sensor generates data based on its functionality. The data should be stored effectively in order to response future user queries [30, 31, 32]. For example, sensor networks that are used in military environments or forests can help collect environmental related values. These networks generally cover a large scope; therefore as time goes by, the amount of gathered data is increasing noticeably. Here, one of the major challenges is how to maintain and retrieve the huge amount of the collected data using lower energy consumption. Using an energy-efficient technique for storing sensor data can substantially prolong the lifetime of the network. A longer life time is a consequence of acquiring the optimum energy-efficient storage mechanism. Responding to semantic web queries would lead to more beneficial achievements. By using semantic web technology, it could be possible to respond more conceptual queries that are closer to human languages. To set the scene for this paper, we identify and discuss related XML technology, which will be surveyed in Section II. Aligning sensors in a hierarchical form can create another significant achievement. We propose aligning sensors in a tree format (Section III). We merge the advantages of using semantic web technologies with the merits of aligning sensors in a hierarchical form briefly. Section IV denotes the proposed novel sensor data storage mechanism which is a hierarchical mechanism based on XML technology, which is one of the core compoeents of current semantic web technologies. Conducted simulations, comparisons and the results are given in Section V. Accordingly, it is shown that our proposed method has better performance along with better life-time in many environments. Finally, the conclusion and future works that can be done for researchers will be discussed in Section VI.

II. RELATED WORKS

Russomanno discusses a broad sensor ontology which is called OntoSensor. OntoSensor primarily adapts parts of SensorML descriptions and uses extensions to the IEEE

Suggested Upper Merged Ontology (SUMO) to describe sensor information and capabilities [28]. The ontology is developed to support sensor information system applications in dynamic sensor selection, reasoning and querying various types of sensor. OntoSensor relies on deep knowledge models and provides extensive information about different aspects of the sensor nodes and devices. The ontology is represented in OWL format and the authors have discussed the advantages of the proposed approach compared to SensorML and XML based solutions. The main enhancement is providing self-descriptive meta-data for the transducer elements and embedded semantics in the descriptions which could be utilized in various sensor discoveries and reasoning applications. Although OntoSensor illustrates a semantic approach to sensor description and provides an extensive knowledge model, there is no distinctive data description model to facilitate interoperable data representation for sensors observation and measurement data [4,9].

A universal sensor observation and measurement data model in collaboration with a sensor specification model create semantic sensor network architecture. Semantic sensor network utilizes semantic Web technologies and reasoning mechanisms to interpret sensor data from physical devices performing observations and measurements. It would support building automated sensor information processing mechanisms to extract additional knowledge from real-time or archived sensor data [10, 12].

Ontology-based description of a service oriented sensor network is discussed in P.Barnaghi. The SWE and Geography Markup Language (GML) classes and properties in collaboration with SensorML, Suggested Upper Ontology (SUMO, In the meantime OntoSensors are used to develop ontology for sensor service description. The ontology consists of three main components ServiceProperty, LocationProperty, and PhysicalProperty [11, 21].

ServiceProperty explains what a service does and properties in the other two components describe the contextual and physical characteristics of the sensor nodes in wireless sensor network architecture. The ontology is represented in OWL form and some initial consistency checking and query results are provided to evaluate the validity of the proposed solution. The system, however, does not specify how complex sensor data will be described and interpreted in a sensor network application.

The proposed framework concentrates on building sensor description ontology for sensor discovery and description of sensor meta-data in a heterogeneous environment. Although sensor device and service description will contribute to build more autonomous sensor networks, providing an interoperable data description model would be also an essential requirement in architecture for semantically enabled sensor networks.

Henson et al describe a prototype application for the sensor Web by using annotated video data [5]. The dataset contains YouTube videos annotated with SensorML and XLINK models with reference to time ontology. The authors discuss how utilizing the semantic leads to retrieve videos by specifying temporal concepts such as “within”, “contains”, or “overlaps” during a time interval query submission. The proposed application demonstrates the main benefits of adding semantics to the sensor network and sensor data. The authors use keyword tagging and meta-data description to provide references to temporal concepts and domain ontologies. An extension to this idea could be seen as providing a universal meta-data structure with a broader scope to accommodate various sensor data types.

III. PRELIMINARIES

A. *Semantic web*

Semantic Web is an extension to the current Web in which the meaningful relationships between different resources are represented in well-defined formats rather than simple links (i.e. href links in HTML). These formats are defined so that they can be processed automatically by machines. Different standard formats are defined by the World Wide Web Consortium (W3C) for representing the semantic Web data. These include Extensible Markup Language (XML), Resource Description Framework (RDF), RDF Schema (RDF-S) and the Web Ontology Language (OWL).

B. *Hierachical Methods*

There are potential benefits in arranging sensors in hierarchical format. Now we have a glance at some benefits of aligning along with most well-known method which is named LEACH (Low-Energy Adaptive Clustering Hierarchy).

Arranging sensors in tree model format constitutes a type of hierarchical model. The following figure illustrates this point in a schematic view.

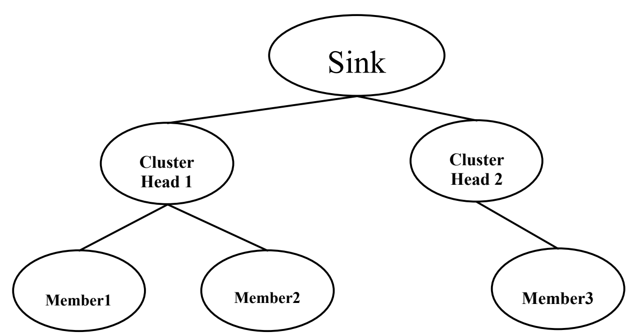

Figure 1: Hierarchical Alignment

Hierarchical Alignment (clustering, see Figure 1 for an example) has a number of benefits, some of which are as follows:

1- **Scalability**: When the sensors are clustered, cluster heads play the role of moderator of their members. This architecture can be easily scaled by minor changes.

2- **Routing table**: Arranging the sensors in hierarchical form causes a significant reduction in the size of the routing tables of sensor nodes. Member nodes need to have only an entry for their cluster head and cluster heads need only an entry for the sink node.

3- **Lower bandwidth consumption**: Using a hierarchical routing strategy (as is used in the clustering structure) leads to two-hop paths from each sensor node to the sink node. This would reduce the bandwidth of communication compared to the other case where each node has to send its own data towards the sink node using a multi-hop routing strategy.

4- **Balanced consumption of energy**: Allowing the cluster head role to be changed from time to time from some sensor nodes to the other ones, the energy consumption of different sensor nodes in the network can be balanced.

A famous hierarchical algorithm called LEACH is demonstrated in the follwoing.

C. LEACH(Low-Energy Adaptive Clustering Hierarchy)

LEACH is an Application Specific Protocol Architecture for wireless networks. In other words, that is an architecture for remote micro-sensor networks combining the ideas of energy-efficient cluster-based routing and media access together with application-specific data aggregation to achieve better performance with the corresponding of system's lifetime-the time that a sensor networks last and run out from working properly- latency and last but not least volume of transmitted data through network. In this paper the LEACH algorithm is used to support our new proposed method.

D. Semantic Sensor Web (SSW) Framework

Sheath and Henson Describes a frameworks that named Semantic Sensor Web (SSW) in which the sensor data is annotated with semantic meta data to increase interoperability as well as providing contextual information essential for situational knowledge. In particular, this involves annotating sensor data with Spatial, temporal, and thematic semantic metadata. The spatial meta-data provides sensor location and data information in terms of a geographical reference system, location reference, or named locations. The temporal meta-data refers to the time interval duration whose sensor data has been captured [2]. Thematic meta-data provides descriptive information about the sensor node which can be derived by sensor data analysis, and utilizing tagging and textual descriptions. The SSW approach presented leverages current standardization efforts of the Open Geospatial Consortium (OGC; www.opengeospatial.org) and Semantic Web Activity of the World Wide Web Consortium (W3C; www.w3.org/2001/sw/) to provide enhanced descriptions and meaning to sensor data. They'll review relevant components. Also relevant but outside the scope of this article is the semantic community Sensor Standards Harmonization Working Group, which takes user perspective [25]. It used RDFa language to annotate sensor data. Sample Semantic annotation of SWE is shown in the following code.

```
<swe:component rdfa:about="time_1"
      rdfa:intanceof="time:Instant">
      <swe:Time rdfa:property="xs:date-time">
            2008-03-08T05:00:00
      </swe:Time>
</swe:component>
```

```
<swe:value name="satellite-data" rdfa:about="Dayton"
            rdfa:instanceof="geo:City">
            0011000111001111 …
</swe:value>
```

This example generates two RDF triples. The first, time_1 rdf:typetime:Instant, describes time_1 as aninstance of time:Instant(subject istime_1, predicate is rdf:type, object istime:Instant). The second, time_1 xs:date-time "2008-03-08T05:00:00,"describes a data-type property oftime_1 specifying the time as a literalvalue (subject is time_1, predicateis xs:date-time, object is "2008-03-08T05:00:00").

E. Semantic Sensor Observation Service (SemSOS):

Sheath and Henson Describes a frameworks that named semantic sensor Web (SSW) in which sensor data is annotated with semantic meta data to increase interoperability as well as provide contextual information essential for situational knowledge. In particular, this involves annotating sensor data with Spatial, temporal, and thematic semantic metadata. The spatial meta-data provides sensor location and data information in terms of a geographical reference system, location reference, or named locations. The temporal meta-data refers to the time interval duration whose sensor data has been captured. Thematic meta-data provides descriptive information about the sensor node, which can be derived by sensor data analysis, and utilizing tagging and textual descriptions [4]. It propose a new method that uses smarter data than raw sensor data and accomplish this by leveraging semantic technologies in order to provide and apply more meaningful representation of sensor data. More specifically, they are modeling the domain of sensors and sensor observations in a suite of ontologies, adding semantic annotations to the sensor data.in other words, it represent data in O&M-OWL form.

The following example shows a sample sensor data in the proposed approach:

```
om:windspeed_1 rdf:type w:WindSpeedObservation .
om:windspeed_1 om:samplingTime om:time_1 .
om:windspeed_1 om:observationLocation om:location_1 .
om:windspeed_1 om:result om:result_1 .
om:result_1 om:value 37 .
om:result_1 om:uom w:MPH .
```

This example shows winspeed_1 that is type of WindSpeedObservation defined in weather(w) ontology. Related SamplingTime is time_1 and its value is 37 MPH.

IV. Methodology and Model

Our NSSSD (short for New Semantic Hierachical Storage for Sensor Data) model is mainly obtained from LEACH model, where we combine the advantages of semantic web concepts with clustering. The results show supeiror performance on our new model. We call the new model as NSSSD, which is elaborated as follows.

To begin with, assume that in a military application, the sensors are spread across the entire environment in order to support enemy recognition. These sensors collect various kinds of data, including temperature and movement updates, etc. By increasing the total sensor numbers, the amount of collected data in the long run are extremely enormous. Most sensors use battery for their energy production. Thus they have a significant limitation in energy. In other words, this resource is critical. In brief, a huge amount of sensor data along with the limitation of most sensors in computational power and especially lack of efficient, long-last and reliable energy suppliers, all these together necessitate the sensors to use battery as their energy supplier. Hence a minor improvement can cause a significant promotion in the life time, which is the time that elapses from network inception to death of the whole network. But the battery industry has faced difficulties in achieving this. So we suggest more efficient software approaches like more efficient algorithms in order to reduce energy consumption of the overall network. Our proposed method is concerning how we should store data so that we can respond to semantic queries effectively and efficiently in terms of energy consumption. For example, requisites are disseminated in semantic web based queires on behalf of users, which may be closer to human language, following with less energy consumption of the network. *NSSSD* is the combination of a hierarchical method with the help of LEACH where sensor nodes are arranged into some clusters with semantic web technolog. Hierarchical method we are using resembles tree structures with 3 levels. Sink node is the root of the hierarchy, cluster heads are children of the sink node. All other sensor nodes are located as leafs of the tree. After arranging sensors we need to schedule data transmissions in order to make sure the safety of the data transmission process is maintained. The proposed method consists of two phases, the set-up phase and the steady-state phase. During the set-up phase, the clustering hierarchy is formed. During the steady-state phase, data transmission is performed as follows: Sensor nodes send their data in XML format to their cluster heads. Then Cluster heads aggregate the received XML-format data and periodically, based on the specified scheduling, send the aggregated data to the sink node, the root of the whole tree. A difference between our method and the LEACH algorithm is that our method concentrates on how data should be stored to achieve better performance. Our method stores data semantically to support more diverse queries but LEACH concentrates on arranging sensors instead of considering the query answering situation of sensors. Futher, our method has better performance in situations that we need to save more energy to achieve longer life time along with responding to various queries that resemble to real human languages instead of querying with very restricted query languages.

V. SIMULATION RESULTS & COMPARISON

The LEACH algorithm is used for clustering concerned sensor networks [23,24]. Cluster heads send data periodically towards the sink node every 2 time units. Simulations are executed for 10 time units. We have assumed that the sink node is fixed and has no mobility. The simulations are conducted through using j-sim simulator for network simulation [3] and protégé 2000 software for semantic web technology [22]. Simulation network dimension is a 100*100 array. Number of sensors in this dimension range is varied from 10 to 150 in a mesh topology. We also use CSMA protocol for our MAC layer that we can set in j-sim. To get more steady data we have run the algorithm for 200 times. Our evaluation uses remaining energy parameter in the simulations. The content of the data we used in simulations can be demonstrated by the following sample data in XML form (see Figure 2):


```xml
<swe:DataRecord definition="urn:ogc:def:property:OGC:atmosphericConditions">
    <swe:field name="AirTemperature">
        <swe:Quantity definition="urn:ogc:def:property:OGC:AirTemperature">
            <swe:uom code="Cel"/>
            <swe:value> 35.1 </swe:value>
        </swe:Quantity>
    </swe:field>
    <swe:field name="WindSpeed">
        <swe:Quantity definition="urn:ogc:def:property:OGC:WindSpeed">
            <swe:uom code="m/s"/>
            <swe:value> 6.5 </swe:value>
        </swe:Quantity>
    </swe:field>
</swe:DataRecord>
```


Figure 2: The XML sample of simulation

As the above example shows, the first part of the data denotes air temperature parameter with a value of 35.1 Celsius and second part denotes the wind speed with a value of 6.5 meter per second. In brief, with the help of semantic web technologies, we can respond to more kinds of queries. This is because we store more meta data about the main data.

In Figure 3, the amount of received data (in KB) in the sink node of the whole network with different number of nodes and different number of clusters is illustrated. In this figure, the horizontal axis shows an ordered pair, (X, Y), where X is the number of sensors in the network and Y shows the number of clusters that the sensor network is divided into. As shown from the figure, increasing the number of sensors results in receiving fewer amounts of data at the sink node. One possible reason for this phenomenon is the effect of the data aggregation. We use data aggregator that sends data in array formats instead of sending each part of the original data.

It may be possible that data is lost. For example, in (150,3), because of inappropriate data aggregation, we observe much data loss. But our analysis shows that most data is successfully aggregated other than lost. It means that data aggregation plays a much more important role in volume reduction of data.

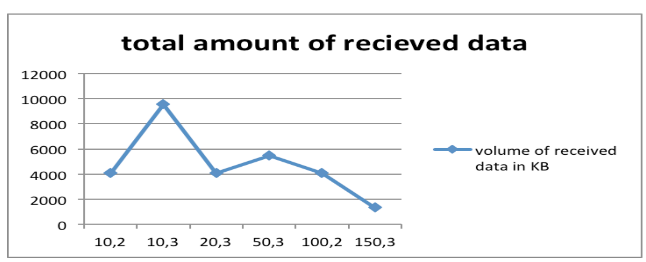

Figure 3: Amount of data received at the sink node

In a nonhierarchical sensor network, an increase of the total number of sensors can cause more data transmission so remaining energy rate of overall sensor network decreases overtly. In hierarchical networks; nodes have been arranged into some clusters; because of bounding sensors into its cluster head, rate of energy consumption reduced. But *NSSSD* combine both advantages of clustering approach and the semantic web one. Using semantic web causes replying to more various queries. We should establish a trade-off between total amounts of received data that we want to handle with the number of clusters to choose which one is more appropriate. In comparison (10, 3) with (20, 3); number of sensors increases but the number of cluster heads is fixed to 3; the slope is decreasing. One possible reason is that cluster heads cannot assign a particular time to each sensor then intervention between sensors happened and some sensors could not win in this competition so their data was lost. But when we compare this with other collected data, we can conclude that there is more possibility that the aggregator plays a major role in this reduction of data. Also as we can see in figure 2, the number of cluster heads plays a key role in the total data transmitted through the network. Another important aspect of the proposed model is how to aggregate data in cluster heads. Better aggregation results in less data transmission so that we can achieve longer life time of the whole network.

Figure 4 shows remaining energy of the sensor nodes during the operation of the network for a scenario in which we have 10 sensor nodes and 1 cluster head. The remaining energy of the cluster head is showed in black. As can be seen from this figure, the energy level of the cluster head is reduced more rapidly than the energy level of the other sensor nodes in the network (for example the red line). Remaining energy of cluster head is $0.999982*10^4$ joule after 2 time units. Energy consumption of cluster head nodes is more than other nodes in the network because the head nodes are also in charge of aggregation. But we have got more powerful features like more scalability, better management and less consumption of the bandwidth. The system can respond to a more variety of queries. We should opt between all suitable approaches for this critical factor [25].

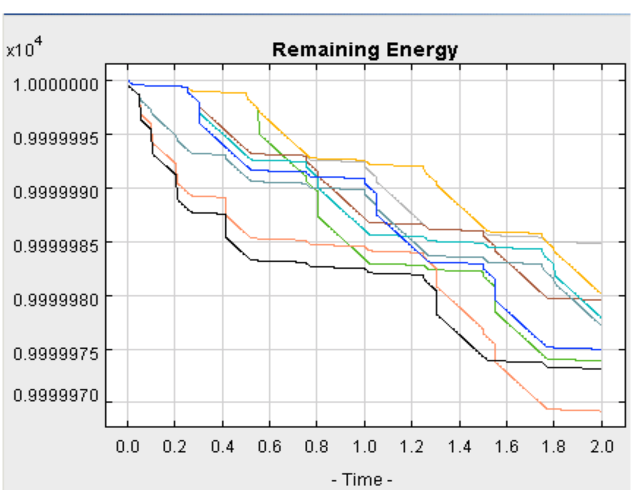

Figure 4: Energy consumption of the network

Finally a comparison between our proposed mechanism and another well-known approach named SSW [3] mechanism in terms of the total data transmission throughout the network is demonstrated in Figure 5. The curve of differences between them is illustrated instead of showing each of them.

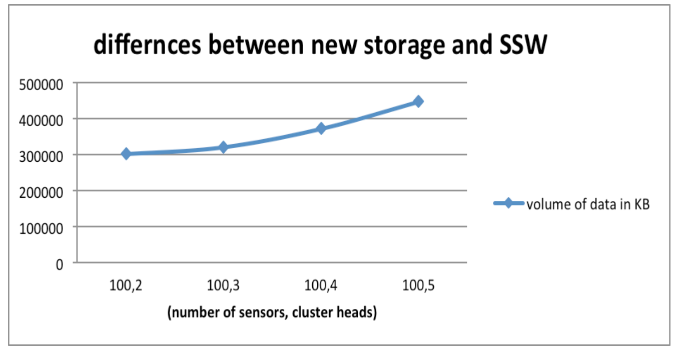

Figure 5: Comparison of new storage and SSW

As it is obvious, variation is in exponential form so we can conclude that *NSSSD* shows better performance. We should opt which method is more suitable for storing the data in sensor networks depending on the specific applications of it. For example, when we have 100 sensors and 2 cluster heads, the difference between the model and SSW is 300152 KB, which means *NSSSD* store the same copy of sensor data as in SSW but using less volume of storage. So our storage method can lead to better performance. Because we want to respond to more kinds of queries with less energy consumption, we should apply semantic models in our storage model. For enegy, we use a hierarchical method to reduce energy consumption. *NSSSD* stores the same sensor data more efficiently in less storage volume than other methods like SSW or SemSOS. One major reason behind this is that we use aggregation in cluster heads with the help of semantic web technologies.

Figure 6 provides a comparison between *NSSSD*, SSW and SemSOS in terms of the amount of data (in KB) received at the sink node. We can see from this figure, our proposed mechanism consumes significantly fewer amounts of storage for storing the same sensor data than the other two mechanisms. For instance, consider the case when we have 100 sensor nodes divided into 3 clusters. In this case, with SemSOS and SSW methods, the total amounts of data stored at the sink node are about 700 MB and 500 MB, respectively, whereas using the *NSSSD* method, this amount is reduced to about 200 MB of data. When we store data in plain-text format, aggregation dose not have any significant effect in reducing the size of data, but when the sensor data is stored and transmitted via XML format, there are efficient aggregators, such as *VERT* aggregator, which can help significantly reduce the amount of storage for the data.

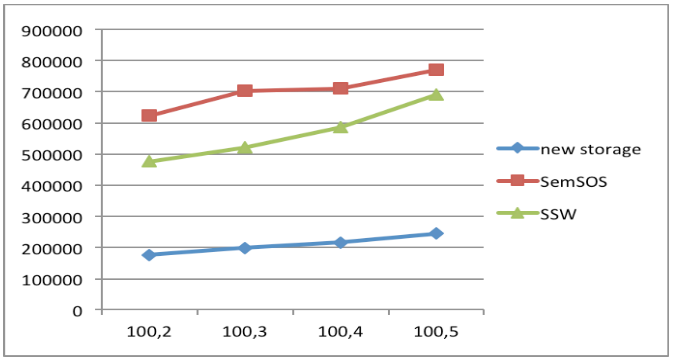

Figure 6: Amounts of received data for three methods (*NSSSD*, SSW, and SemSOS form) in KB

VI. CONCLUSION

In this paper, a new semantic hierarchical sensor sata storage is introduced and formalized. It divides sensors into different clusters and sends data semantically. Each member node sends its data in semantic form to its corresponding cluster head. Cluster heads then aggregate the received data and send to the sink node. We have integrated the benefits of sending data semantically and arranging the data hierarchically. We have showed that *NSSSD* supports responding to more diverse queries in a semantic way with the combination of arranging sensors in a hierarchical mode to gain the advantages. We are planning on extending this new-born method like sending data in a more semantical way.

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